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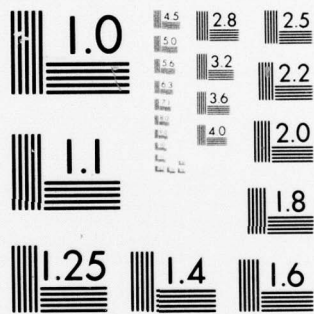APR 77   J E CREEDON, S SCHNEIDER

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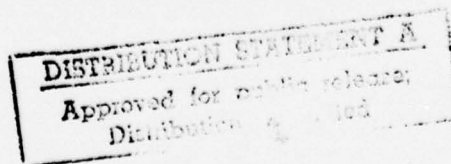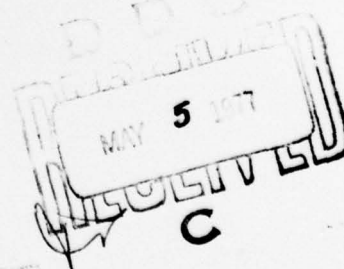Research and Development Technical Report

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MEGAWATT AVERAGE POWER ADIABATIC MODE THYRATRONS

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Electronics Technology & Devices Laboratory

April 1977

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US ARMY ELECTRONICS COMMAND FORT MONMOUTH, NEW JERSEY 07703

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

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the device was capable of being operated reliably at 22.5 amperes of average
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MEGAWATT AVERAGE POWER ADIABATIC MODE THYRATRONS

by

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ABSTRACT

Significant impact on the size and weight of high energy pulse systems having short on times can be obtained by designing components to operate in the adiabatic mode. In the specific case of the thyratron switch the mass of the cathode anode and grid elements can be used as internal heat sinks. This allows the average current capability and thus the power handling ability to be increased several times over the normal steady state value for short operating times. Several thyratrons designed for short term, high peak and average power switching applications have been studied at average powers approaching one megawatt. In addition, an off the shelf HY-5 was operated in the adiabatic mode and it was found that by modifying the cathode structure the device was capable of being operated reliably at 22.5 amperes of average current at a peak voltage of 15 kilovolts.

Discussion

Adiabatic Mode of Operation

Recently, there has been interest in developing modulators that operate for short on-periods of one minute or less at peak and average powers substantially above those controllable with a single state-of-the-art switching device. Off-times, however, are relatively long and may be from several minutes to several hours. Since significant heat losses by conduction and radiation will not occur until a substantial temperature rise in the specific element occurs, the device can be operated in the adiabatic mode. For this type of an operating mode, the temperature rise of the internal elements are proportional to the total energy dissipated and the mass of the element and inversely proportional to the heat capacity. If the pulse width is long, that is, greater than a few microseconds, anode and grid heating effects associated with commutation will not be significant. For this condition, the internal dissipation of the thyratron will be directly proportional to the average current.

High Average Power Thyratron Design

Figure 1 shows a high average power switch design superimposed on a 8 gap thyratron which differs in several ways from devices designed for radar applications. One difference is that high voltage hold-off capability is obtained by using a multiple cavity-grid structure rather than a stack of

1

parallel plate grids. The problem with the latter approach is that in practice it is limited to two gaps when operation in air is desired. The limitation occurs because the external voltage stress must be less than 10 kilovolts/inch to prevent flashovers across the insulators while the internal spacing is adjusted to give a voltage stress in hydrogen or deuterium of nearly 200 kilovolts/inch. The disproportionate difference in the internal and external spacing requirements results in the use of deep cup electrodes which are not suitable for unlimited stacking of grids. The gradient grids must have the same physical configuration which permits easy construction and results in equal capacitance distribution and short paths for good electrical and heat conduction. All of the above design characteristics can be obtained by using wide spaced cavities between the high voltage grids.

In operation the cavities are made nearly field free except for a small value required to ensure complete internal breakdown and plasma propagation. One disadvantage of the wide spaced, low voltage hold-off cavities is that recovery times are long. To increase the speed of cavity deionization, which is predominantly governed by ambipolar diffusion mechanisms, inverted metal cups are placed in the cavity to increase the surface to volume ratio.

Another departure from conventional thyratron design is the incorporation of the virtual anode. This design concept offers two advantages. One is that it provides a defocusing region for high voltage electrons formed during the breakdown or commutation period prior to their collection by the anode. Substantial numbers of electrons are accelerated up to full anode potential during commutation, and in the conventional geometry the beam waist caused by the focusing action of the high field occurs at a distance approximately equal to the grid anode spacing. The high electron energy is then dissipated in a small area resulting in hole drilling and localized anode heating. The resulting sputtering of metal atoms degrades both inverse hold-off and recovery characteristics. Another advantage of the virtual anode design is that it provides a large reservoir of gas molecules behind the anode. During high peak current operation pronounced ion pumping as well as transient clean-up may take place which deplete the anode grid region of neutral gas. Gas diffusion from the upstream virtual anode cavity temporarily compensates for these losses until circulating gas flow and reservoir replenishment actions are established.

Megawatt Average Power Switches (MAPS)

Four MAPS type switches are being developed. Their electrical and mechanical objectives are summarized in Table 1. Three of them, the MAPS 70, 80 and 250 are the cavity grid design. The initial MAPS 40, shown in Figure 2, is designed with a plane parallel 2 gap structure with a virtual anode. The MAPS 70 is shown in Figure 3. This device is a three gap two cavity deuterium filled device having a 5000 cm^2 cathode. Internal water cooling is provided to all of the grid elements. Approximately five of the devices have been fabricated by EG&G to date. In general, leaks in the seals for the cooling channels

2

have limited the performance of this design. A smaller diameter, 4 gap air cooled version, the MAPS 80 has also been studied.

The MAPS 250 is being developed for use in a Blumlein Modulator described in a paper[1] by Wright and Schneider. The MAPS 250 has 10 gaps and 9 cavities and a 2000 cm^2 oxide coated cathode. The cathode is mounted in a steel housing, 6 inches in diameter and the convoluted ceramic high voltage super structure is 4 inches in diameter. The cavity spacers are graduated in length and are longer at the top of the tube because of the external spark over probability during commutation. Four MAPS 250 devices have been fabricated by EG&G. Table 2 summarizes the maximum operating levels obtained to date.

The MAPS 70 has demonstrated operation at 80 percent of the voltage and at 87 percent of the average current objectives. The MAPS 250 has operated at 80 percent of the objective voltage level on single shot and 70 percent of the objective at 50 hertz. The pre-MAPS 40 operated at objective voltage and peak current and switched over 80 percent of the objective average power before developing a leak in an anode seal. Two other tubes, the KU 375 and the HY 5000 series, which were not specifically designed for the adiabatic modes have also been tested. The KU 375 is a 3 gap version of IT&T's KU 275.

The HY 5001 and HY 5002 are modifications of the standard EG&G HY 5. The HY 5 was evaluated at 22.5 amperes average current with a 30 second on-time and a 4 1/2 minute off-time. After approximately 50 on-off cycles, the devices exhibited a missing pulse characteristic which was found to be due to severe distortion of the cathode baffle. An 0.060 mils molybdenum baffle was then substituted for the 0.040 mils copper. Over 1000 fault free cycles at 22.5 amperes have been demonstrated for the 5002. The 5001 had 3 pre-firings in a similar number of on-off cycles. The HY 5001 had a conventional grid while the 5002 had a heavy external flange.

Discussion of Results

Several thyratron designs have been evaluated at peak powers up to 800 megawatts and average powers up to 800 kilowatts where the on-time has varied from 5 to 30 seconds. Peak currents of 40 kiloamperes have been achieved from oxide cathode with areas of 2000 cm^2 for 10 microsecond pulse durations. Peak voltages of 40 kilovolts have been demonstrated with 2 gaps but dc hold-off and pre-fire reliability is marginal and 3 gaps appear necessary for reliability. Inverse clipping occurs and limits recovery. The virtual anode design appears to be an advantage since the arc spot associated with the inverse conduction is isolated from the high voltage hold-off regions. Root mean square currents of over 1200 amperes have been demonstrated in cathodes having area of 1000 and 5000 cm^2. The peak and average current limits observed in these tests were primarily facility limited and much higher values are believed to be obtainable. Dc resonant charging and a resistor load was used for all of the testing. Recharging of the pulse forming network was at a rate of 85 - 120 hertz.

3

Acknowledgment

The contribution of J. McGowan for his performance of many
evaluation tests are acknowledged.

Reference

1. Wright, W., and Schneider, S.,: "A Blumlein Modulator for a
    Time-Varying Load," IEEE Conference Record, No. 76CH1045-4ED,
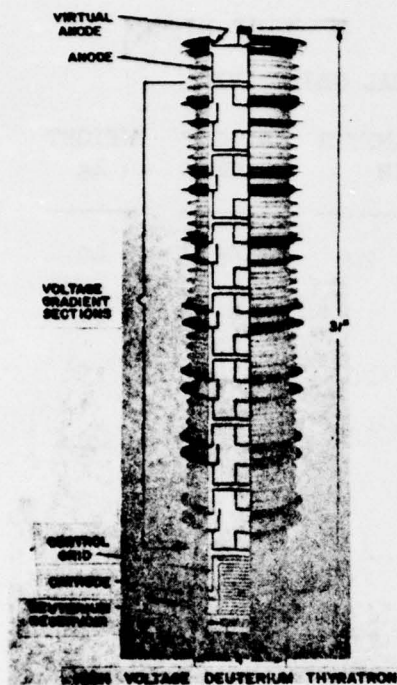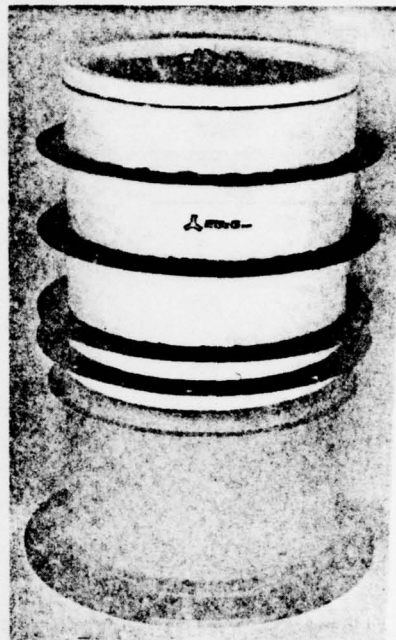   (February 1976).

Figure 1.

VIRTUAL ANODE

ANODE

VOLTAGE GRADIENT SECTIONS

CONTROL GRID

HIGH VOLTAGE DEUTERIUM THYRATRON

MAPS 40
Figure 2.

MAPS 70
Figure 3.

TABLE 1

MAPS ELECTRICAL AND MECHANICAL OBJECTIVES

TYPE	PEAK VOLTAGE kV	PEAK CURRENT kA	AVERAGE CURRENT A	DIAMETER CM	HEIGHT CM	WEIGHT kg
MAPS 70	70	5	30	20	68	40
MAPS 250	250	20	4	10	140	25
MAPS 40	40	40	50	20	38	15
MAPS 80	70	5	30	12	72	—

TABLE 2

SUMMARY OF RESULTS - ADIABATIC MODE OPERATION

TYPE	PEAK VOLTAGE kV	PEAK CURRENT kA	AVERAGE CURRENT A	PULSE WIDTH µs	LIFE
MAPS 70	56	4	26	20	20
HY 5001	15	4	22.5	20	$>10^6$ SHOTS
HY 5002	20	8-9	30-32	20	$>10^6$ SHOTS
MAPS 250	200	13	3	5	$>10^6$ SHOTS
MAPS 250*	40	20	25	10	---
MAPS 40	40	40	42	10	---
MAPS 80	40	20	20	10	---
KU 375	40	20	25	10	---

*Using 5 Gaps

6